

**WHAT IS CLAIMED IS:**

- 1           1.       A method for determining vibration amplitude limits to detect faults in  
2       mechanical equipment, comprising:  
3                   estimating a data probability distribution based on data for the mechanical  
4       equipment; and  
5                   utilizing the data probability distribution to calculate the vibration  
6       amplitude limits.
- 1           2.       The method of Claim 1 further comprising removing outlier data.
- 1           3.       The method of Claim 2 further comprising calculating the vibration  
2       amplitude limits as a function of frequency for a substantial portion of the frequency  
3       spectrum.
- 1           4.       The method of Claim 1 wherein the data probability distribution is  
2       calculated using statistics and historical data of the mechanical equipment.
- 1           5.       The method of Claim 4 further comprising specifying importance levels  
2       for certain frequencies.
- 1           6.       The method of Claim 5 wherein the certain frequencies comprise  
2       frequencies for at least one of a motor, a compressor, or a gear.
- 1           7.       The method of Claim 6 further comprising obtaining vibration spectra  
2       comprising individual spectrum for the mechanical equipment from a database.
- 1           8.       The method of Claim 7 further comprising calculating a frequency for the  
2       individual spectrum and identifying the individual spectrum having a smallest number of  
3       frequency lines.



1           16.     The method of Claim 15 wherein a  $d$ -dimensional kernel density estimate  
2 is generally written as:

$$p(x) = \frac{1}{n} \sum_{j=1}^n |H|^{-1/2} K\left(H^{-1/2}(x - x_j)\right)$$

3  
4           where  $K(u)$  is a  $d$ -dimensional kernel,  $H$  is a bandwidth matrix, and  $|\cdot|$  denotes a matrix  
5 determinant.  
6

1           17.     The method of Claim 4 further comprising detecting one or more faults in  
2 the mechanical equipment.

1           18.     The method of Claim 1 wherein the mechanical equipment comprises one  
2 or more HVAC chillers.

1           19.     A method for detecting faults in a chiller based on vibration amplitude  
2 limits, comprising:

3                     calculating vibration amplitude limits of the chiller using statistics and  
4 historical data for the chiller;

5                     estimating an at least two-dimensional density estimate; and

6                     weighting the historical data based on when the historical data was  
7 generated;

8                     wherein the vibration amplitude limits are calculated as a function of  
9 frequency for an entire frequency spectrum.

1           20.     The method of Claim 19 further comprising removing outlier data.

1           21.     The method of Claim 20 wherein the at least two-dimensional density  
2 estimate utilizes frequency and amplitude directions of the frequency spectrum.

1           22.     The method of Claim 21 wherein the at least two-dimensional density  
2 estimate is a  $d$ -dimensional kernel density estimate.

1           23.     The method of Claim 22 wherein the  $d$ -dimensional kernel density  
2     estimate for point  $x$  of a dataset with  $n$  data points is given by:

$$3 \qquad p(x) = \frac{1}{n} \sum_{j=1}^n |H|^{-1/2} K \left( H^{-1/2} (x - x_j) \right)$$

4     where,  $x_j$  is the  $j^{\text{th}}$  observation of the dataset,  $K(u)$  is a  $d$ -dimensional kernel,  $H$  is a  
5     bandwidth matrix, and  $|\cdot|$  denotes a matrix determinant.  
6

1           24.     The method of Claim 22 further including obtaining vibration spectra  
2     comprising individual spectrum for the chiller from a database.

1           25.     The method of Claim 24 further comprising calculating a frequency for  
2     the individual spectrum and identifying an individual spectrum having the smallest  
3     number of frequency lines.

1           26.     The method of Claim 25 further comprising calculating noise bandwidths  
2     and a largest noise bandwidth.

1           27.     The method of Claim 26 further comprising collecting vibration data from  
2     all spectra in a given frequency range.

1           28.     The method of Claim 19 further comprising calculating a conditional  
2     kernel density.

1           29.     The method of Claim 28 wherein calculating the conditional kernel  
2     density comprises estimating an unknown probability density for a given dataset.

1           30.    A method for determining vibration amplitude limits of a mechanical  
2 device comprising:  
3                   identifying a mechanical device and a frequency range for a spectrum to  
4 be analyzed;  
5                   retrieving vibration spectra comprising individual spectrum for the  
6 mechanical device and the frequency range;  
7                   calculating frequency for the individual spectrum;  
8                   identifying the individual spectrum with a smallest number of frequency  
9 lines;  
10                  calculating noise bandwidths and a largest noise bandwidth;  
11                  removing outlier data;  
12                  calculating conditional kernel density; and  
13                  calculating vibration amplitude limits to detect faults in the mechanical  
14 device.

1           31.    The method of Claim 30 wherein the mechanical device comprises a  
2 chiller for an HVAC system.

1           32.    The method of Claim 30 wherein the vibration spectra for the mechanical  
2 device and the frequency range is obtained from a database.

1           33.    The method of Claim 32 wherein calculating conditional kernel density  
2 comprises estimating an unknown probability density for a given dataset.

1           34.     The method of Claim 33 wherein the probability density estimate at a  
2 point  $x$  for a one-dimensional dataset with  $n$  data points is given by:

$$3 \qquad p(x) = \frac{1}{nh} \sum_{j=1}^n \kappa \left( \frac{x - x_j}{h} \right)$$

4           where,  $x_j$  is the  $j^{\text{th}}$  observation of the dataset,  $h$  is a bandwidth that characterizes a spread  
5 of the kernel, and  $\kappa(\cdot)$  is a kernel density function that is symmetric and satisfies the  
6 condition:  $\int_{-\infty}^{\infty} \kappa(u) du = 1$ .  
7

1           35.     The method of Claim 33 wherein the kernel density estimate is at least a  
2 two-dimensional kernel density estimate utilizing frequency and amplitude directions of  
3 the frequency spectrum.

1           36.     The method of Claim 35 wherein a  $d$ -dimensional kernel density estimate  
2 is given by:

$$3 \qquad p(x) = \frac{1}{n} \sum_{j=1}^n |H|^{-1/2} K \left( H^{-1/2} (x - x_j) \right)$$

4           where  $K(u)$  is a  $d$ -dimensional kernel,  $H$  is a bandwidth matrix, and  $|\cdot|$  denotes a matrix  
5 determinant.  
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